AIC-3
NM-235

UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Research Administration
Bureau of Agricultural and Industrial Chemistry

INDUSTRIAL ALCOHOL

By

W. W. Skinner, Chief
Bureau of Agricultural and Industrial Chemistry

Revised by

P. Burke Jacobs, Senior Industrial Analyst
Commodity Development Division
Northern Regional Research Laboratory
Peoria, Illinois

March 1943

INDUSTRIAL ALCOHOL[1/]

Introduction

Ethyl alcohol, commonly called "grain" alcohol, and in former days known as "spirits of wine", has been known and used since the dawn of history, principally in the form of fermented beverages. Ancient races knew how to recover the intoxicating principle from such beverages by a crude form of distillation. Originally alcohol was recovered as dilute, impure solutions from fermented fruit (wines) or grain, hence the origin of the earlier names.

For several centuries it has been customary for governments to levy a tax on alcohol solutions and distillates, thus raising revenue as a form of penalization or restraint upon the use of intoxicating beverages containing alcohol. With the gradual production of more highly purified "spirits" suitable for use as a chemical agent or raw material in industry (i.e., "nonbeverage" use) during past decades, it gradually became evident that payment of a beverage tax upon a chemical commodity introduced unnecessary costs into certain manufacturing operations. In 1906, the U. S. Congress passed an act permitting the sale of tax-free alcohol for industrial purposes, if certain precautions were taken to prevent the illegal use of same as a beverage, since all alcoholic beverages were and still are subject to taxation. The industrial alcohol industry is separate and distinct from the beverage alcohol industry, from a legal standpoint.

Industrial Alcohol Defined

The term "industrial alcohol" today includes pure alcohol, for medicinal, scientific, or special solvent use, and mixtures of alcohol with certain denaturing agents in accordance with the regulations of the Bureau of Internal Revenue, whereby the alcohol is "denatured", i.e., rendered unfit for internal human consumption. Pure alcohol is also used as an added component of certain beverage spirits, as in the manufacture of "blends" (alcohol-water dilutions of straight whiskey), and in the manufacture of gin, cordials, etc.; when so used, alcohol is classified as industrial alcohol, as produced, but as beverage alcohol, as consumed.

[1/] The Bureau of Chemistry first published this circular in 1922, under the title "Information on Industrial Alcohol". It was revised and reissued by the Bureau of Chemistry and Soils in May 1936, and again in January 1938 as MC-22. Because of recent developments in this field it is now reissued by the Bureau of Agricultural and Industrial Chemistry in a further revised form (1943).

This circular presents a general discussion of the production and use of industrial alcohol. For more detailed information the reader is referred to the appended list of books and articles, many of which should be available in local libraries.

"Beverage" spirits are not included in the term "industrial alcohol", although these distillates contain alcohol and are produced in an analogous manner. Whiskey, brandy, and rum, for example, while consisting principally of ethyl alcohol and water, (usually 50 percent alcohol or less) contain, in addition, small quantities of so-called congeneric substances that impart characteristic flavors and bouquets, which are lacking in mixtures of pure alcohol and water. Such beverage spirits are produced under special regulations and conditions, and are distilled at lower concentrations and sold practically as produced, with emphasis upon taste or bouquet rather than upon alcohol concentration. In order to govern the composition and content of these congeneric substances in the several types of beverage spirits intended for human consumption, care in the selection of raw materials and specialized steps in the process of manufacture are essential. In the manufacture of alcohol for industrial uses, however, high alcohol concentration and purity are stressed. Such production also necessitates careful supervision over raw materials, manufacturing processes, and denaturing agents, in order to secure adequate yields and quality, but the end-product objective is different.

Malt beverages (beer) and wines also are not classed as industrial alcohol. These are fermented products, containing alcohol, which are sold in original form, without distillation. Their alcohol concentrations are relatively low (beer 3-5 percent, wines 12-20 percent).

"Industrial alcohol" therefore includes pure alcohol, "specially denatured" alcohol, and "completely denatured" alcohol, since all these find various industrial (nonbeverage) uses. Pure alcohol used in medicine, pharmacy, flavoring extracts, beverage blends, etc., while classed as industrial alcohol, is taxed in the same manner as beverage spirits. Pure alcohol may be tax-free in certain instances, as when used for scientific purposes. Denatured alcohol is tax-free, but sale of "specially denatured" alcohol is restricted by a permittee system, since many of the formulae use specialized denaturants which yield a product that is essentially pure alcohol. "Completely denatured" alcohol, which is sold without restriction (in reasonable quantities), contains sufficient malodorous and obnoxious denaturing agents to wholly prevent use or recovery as pure alcohol. This grade frequently furnishes a sales outlet for certain concentrated distillates that accumulate in the production of pure alcohol and are not ordinarily re-refined (under existing regulations) for pure spirit purposes because of "off" odor, taste, or composition. Such "off" grades of alcohol can sometimes be used in special denaturing formulae, but usually these formulae require the use of reasonably high-grade spirit. Because of the usual percentages of "off" grade alcohol normally produced in the alcohol refining operation, a certain yearly basic production of completely denatured alcohol is to be anticipated. If met by dull market conditions, a surplus may arise and indirectly affect the market price and refinery operation gallonage. A considerable amount of completely denatured alcohol is marketed as an "anti-freeze" agent for automobile radiators and thus has a seasonal aspect. Limited sale during a mild winter may cause stocks to accumulate under normal trade conditions.

Sources of Alcohol

Ethyl alcohol may be derived from four classes of raw materials: (1) Saccharine materials (containing sugar, such as molasses, sugar beets, sorgo, sugarcane, etc.); (2) starchy materials (cereal grains, potatoes, etc.); (3) hydrocarbon gases (such as ethylene, and acetylene, found in natural gas, coal gas, and waste gases from certain industrial processes such as petroleum refining, or especially prepared for the manufacture of alcohol); and (4) cellulosic materials (wood, agricultural residues) and the waste sulfite liquor from paper-pulp mills which contains sugars from cellulose and hemicellulose hydrolysis.

In the first two cases the traditional fermentation method of alcohol production is employed. Either the raw material is one of the simpler sugars, in which case it can be fermented directly to alcohol by one of a number of varieties of yeast; or it is one of the more complex carbohydrates (starches, etc.), which must first be broken down to a simpler compound (sugar) before the yeast can do its work. The third case, which represents chemical synthesis, has attained extensive commercial importance in recent years. No fermentation process is involved. In the last instance the normally unfermentable cellulosic constituents of wood or vegetation may be converted directly to fermentable sugars by hydrolysis with mineral acids. Similar production of fermentable sugars is accomplished to a small extent in the production of paper pulp from wood by the sulfite process, the sugars resulting from the chemical treatment remaining in the waste liquor as a dilute solution. After suitable purification of the sugar solutions, as derived by either method, yeast fermentation may be conducted, as in the case of grain.

Saccharine Materials

Byproduct cane molasses (blackstrap) forms a very acceptable and cheap source of raw material for the production of alcohol. Most of the industrial alcohol produced in the United States for many years has been from this source. Molasses has an advantage over starchy materials such as potatoes and corn, in that most of its carbohydrate (sugar) is already in suitable form for transformation into alcohol by the action of yeast, whereas the starch-bearing raw materials must first be treated with enzyme, such as diastase, (or with dilute acids) to convert the starch into sugar before fermentation can take place. In general, byproduct or waste molasses consists of the residues from evaporated sugarcane juice, after the extraction of the crystallizable sugar. Such molasses contains from 50 to 60 percent of sugars, 55 percent probably being a fair average. The sugars represent a mixture of glucose with some sucrose which cannot be economically crystallized out in the sugar extraction process. About 2-1/2 gallons (29.4 lbs.) of such molasses are required to produce a gallon of 95 percent alcohol, the actual yield being usually about 90 percent of the theoretical. Most of the blackstrap molasses used for alcohol manufacture in this country is imported from Cuba, a relatively smaller quantity being obtained from Puerto Rico and other sugar crop areas. In recent years Cuba has also produced an increasing amount of "invert", or "high test" molasses, in lieu of producing raw

crystallized sugar, since such molasses could enter the United States without reference to sugar import allocations, when intended for industrial and not for food use. In this case the entire raw cane juice was inverted with acid or enzymes, with no removal of crystallized sugar, and evaporated to about 75 percent total sugar content. Production of this grade of molasses enabled the sugar plantations to continue operations in a restricted sugar market. The situation has been somewhat modified by war conditions.

In France, the sugar beet constituted one of the most important sources of alcohol, but in the United States alcohol is not made directly from beets. The juice of the sugar beet contains a variable proportion of fermentable sugar, and beets of good quality should yield approximately 23 gallons of 99.5 percent alcohol per ton. A small amount of the beet molasses obtained as a byproduct in the manufacture of beet sugar has been used occasionally for the production of alcohol, but the amount is negligible. It is used more largely for the production of yeast and citric acid. This molasses has a high value as a stock feed ingredient, when mixed with blackstrap molasses.

Under certain conditions in the world sugar markets, it may perhaps be economically feasible to produce industrial alcohol by the direct fermentation of sugarcane juice. Actual plant operations in Cuba, as reported in 1933, indicated that 95 percent alcohol might be manufactured from sugarcane juice at a cost of around 7.2 cents per gallon, including charges for materials, labor, conversion, supervision, and taxes, at values then current. Computing sugar in juice at 1 cent per pound ($2.00 per ton for cane), alcohol costs of about 20 cents per gallon are indicated. Alcohol has also been produced very cheaply in tropical countries from the sap of the nipa palm and similar sugar sources. Pineapple waste, which contains small amounts of sugar, has served as a source of industrial alcohol in Hawaii.

Because no preliminary grinding and conveying machinery and supplemental feed recovery equipment are ordinarily required, molasses alcohol plants are usually simpler in design and involve lower capital and operating costs than plants manufacturing alcohol from grain. The general process of manufacturing alcohol from blackstrap molasses is as follows: Molasses from the storage tanks is pumped to mixers, where sufficient warm water is added to reduce the sugar content to about 12 to 16 percent, a dilution of approximately 1:4 or 1:5. Sulfuric acid is then added to bring the acidity to the optimum (pH 5.4 to 5.6) and, if the molasses is deficient in available nitrogen, ammonium salts are added to stimulate yeast growth. After thorough mixing and pre-sterilization the mash is brought to about 70°-80° F. and pumped to the fermenting vats. Here a quantity of active yeast suspension is added (3 to 5 percent by volume). The fermentation starts immediately, and is complete in 28 to perhaps 51 hours, depending upon the temperatures used. The carbon dioxide produced is usually scrubbed with a water spray to remove alcohol, and allowed to escape into the air, although it may be recovered by compression or liquefaction for distribution in cylinders, or in solidified form as "dryice", if a commercial demand for it exists. When the fermentation is complete, the fermented liquor or "beer", as it is usually called, is pumped to an exhausting column, where the alcohol is separated at

40-70 percent concentration, depending on the column design, by the use of steam. The remaining watery solution ("slop" or "stillage") is discharged from the base of the column and is usually discarded. The "slop" is sometimes concentrated and used as "core binder" in foundries and as a briquette adhesive, or burned to yield a potash fertilizer material. A subsequent redistillation of the first alcoholic distillate produces 95 percent alcohol and a byproduct known as "fusel oil". The 95 percent alcohol may be denatured and sold as such, or it may be approximately dehydrated to yield so-called "anhydrous" alcohol of about 99.5 percent concentration by volume.

Starchy Materials

The principal starchy materials which may be used in making industrial alcohol are: (1) The cereals (corn, grain sorghum, oats, rye, wheat, barley, and rice); (2) potatoes; (3) sweetpotatoes; and (4) miscellaneous crops such as Jerusalem artichokes (Girasole). Actually only corn, grain sorghum, wheat, rye, barley, and potatoes have been used commercially in this country. Rice has been used in the Orient.

(1) Corn, our most abundant cereal, was used to some extent in the manufacture of industrial alcohol previous to the present war, but such use was limited by the cost. Wheat, rye, barley, and other cereals usually command relatively high prices as foodstuffs, which restrict their use as raw materials for alcohol, except for beverage alcohol manufacture. Barley in the form of malt is used rather extensively as an enzymic agent for the conversion of starch to fermentable sugar, but otherwise finds little application in the production of industrial alcohol in the United States. The use of such grains has been mostly limited to beverage alcohol production.

In the manufacture of alcohol from corn by the conventional process the first step involves cleaning and grinding the grain, with or without the removal of the oil-bearing germ. Suitably ground meal is placed in a batch cooker equipped with a motor-driven agitator. Some water is added (about 20 gallons per bushel of grain), and the slurry is then heated with steam under pressure (up to 40-50 pounds gage) to gelatinize the starch. The resulting softened and disintegrated material is cooled to saccharifying temperature (140° - 145° F.),and the starch is converted to sugar by the addition of malt (usually as a cold-water suspension), the saccharification being effected by the malt enzyme, diastase. The malt commonly used is made from germinated barley, although rye and wheat malts are also used. It is, however, also possible to saccharify starch by the use of an enzyme produced by molds (the "amylo" and "moldy bran" processes), or by hydrolysis with dilute mineral acids. Recently the continuous cooking of grain slurry has been introduced to replace the batch operation.

The saccharified mash, however obtained, is cooled to the fermenting temperature of 70°-86° F., transferred to the fermenting vats, adjusted to a pH of about 5.4 to 5.6, and inoculated with yeast. The remainder of the process, except for the disposal of the slop, is in general the same as that described for the production of alcohol from molasses.

The slop or waste resulting from the fermentation of the cereal grains may be used for feeding livestock. It is rich in protein (28-30 percent on dry basis) and vitamins, particularly of the B complex (thiamin and riboflavin) with some pro-vitamin A, and has a high feeding value, particularly when the cereal germ is not removed. This slop contains suspended and dissolved solids, and may be concentrated and fed in the wet form, or it may be dried and bagged. In the dried form it is known as "distillers' grains". Distillers' dried "light" grains represent only the screenable solids of the slop, while distillers' dried "dark" grains represent the complete recovery of both dissolved and suspended material. Recently a few firms have recovered the dissolved solids as a separate product, which is dried and sold as distillers' dried solubles. (One ton of corn yields about 550 to 600 pounds of distillers' grains, or about 15.5-18.0 pounds per bushel, maximum recovery).

(2) Potatoes have been very largely used for alcohol production in Germany, where they were an important agricultural crop. Special types of potatoes of high starch content were developed for the purpose, and the technological features of handling the material in small plants were extensively worked out. The manufacture and distribution of alcohol in Germany has been controlled by the government. The use of potatoes for alcohol production in pre-war years was designed to benefit agriculture through advantages derived from crop rotation and other benefits of an indirect, although important economic character. In the United States the manufacture of alcohol from potatoes has never attained any commercial importance. It has not been an attractive commercial venture, because corn and molasses represent more abundant, more concentrated, less perishable, and relatively cheaper sources of alcohol than potatoes. The State of Idaho has operated an experimental alcohol plant in an effort to deal with the potato cull problem.

(3) Sweetpotatoes have become of interest as a source of industrial starch, in recent years. Some varieties may contain 30 percent or more of fermentable matter. The culls of this crop might receive favorable consideration as a source of industrial alcohol, as the price which could be paid for them would be about the same as that offered by starch factories. Likewise, the washings from the starch tables might be utilized for alcohol production. However, recovery costs from dilute solutions may be sufficiently high to make such a process uneconomical. With indicated yields of 300 to 400 bushels to the acre, sweetpotatoes might represent yields of alcohol, per acre, comparable to any cereal crop in the United States. Sweetpotatoes, however, are difficult to store, and thus present a special handling problem. From a technological standpoint, processing sweetpotatoes into alcohol would probably be done in the same manner as other starchy crops; that is, steaming and crushing of the raw material, saccharification of the starch, and fermentation with yeast. The slop, skins, etc. may be used as cattle food.

(4) The Jerusalem artichoke (or wild sunflower) tuber has been mentioned as a possible source of industrial alcohol. Inulin, the chief carbohydrate constituent, is easily broken down into levulose, a fermentable sugar. The production of alcohol from artichokes presents much the same technological

features as from sugar beets. Commercial crops have been planted, in France, but no significant production has ever been achieved in the United States. As in the case of all other farm crops, the use of artichokes for alcohol production would be wholly dependent upon the financial return which accrues to the farmer and processor. At present, this source does not look particularly promising. Whether cultural studies might lead to improvement in yield per acre and carbohydrate content is a question which lies beyond the scope of this circular.

(5) Interference with the normal transportation of the usual molasses supply from Cuba, etc., due to World War II, has recently caused a shift in the industrial alcohol industry due to inadequate supplies. Plants, previously using molasses only, have been forced to install equipment suitable for handling, grinding and processing whole grain, or alternatively have resorted to the use of special milled grain products. The use of granular flour or meal as raw material has certain advantages for molasses-type plants in that: (a) this material is of relatively higher starch (or fermentable) content than the original grain; (b) the necessity of installing grinding machinery is eliminated; and (c) grain byproducts (bran, etc.) suitable for stock feed are mostly separated by the milling industry and need not be recovered at the alcohol plant, thus avoiding the necessity of installing recovery equipment and of expanding boiler plants to secure the extra steam requirement needed to process slop to recover byproduct grains. Furthermore, the use of newly discovered continuous cooking methods eliminates the necessity of installing expensive pressure-cooking equipment. Because of these facts, molasses alcohol plants have been able to accomplish production from grain with a minimum of change or additions.

Because of the present relatively large wheat surplus, and the fact that wheat ordinarily does not find industrial uses or is not so acceptable for feed as corn, stress has been temporarily placed on the substitution of wheat for corn as a source of alcohol to conserve cornstocks. The wheat protein (gluten) may introduce, however, certain problems in foaming of mashes and fouling of byproduct recovery equipment which are not experienced in the same degree with corn. Such problems are not sufficient to interfere with the industrial utilization of wheat, although relative plant output capacities may be slightly diminished. Mixtures of corn and wheat are handled without trouble in usual equipment when the wheat percentage is below 50 percent of the mixture, and plant output capacities are not adversely affected. Use of granular wheat flour actually permits increased unit production, since the starch content is relatively higher. Wheats with lower protein content and higher starch percentages may prove to be more acceptable as distillery materials than high-protein wheats which would yield less alcohol because of their usually lower relative starch content.

Cellulosic Materials

(1) Mill and Forest Waste and Trees

The utilization of wood for the production of ethyl alcohol comprises two essential steps: (1) The hydrolysis of the cellulose of the wood to simple

sugars; and (2) the fermentation of these sugars to alcohol by yeast in the usual manner. There are two general processes for carrying out the hydrolysis step. The cellulose may be saccharified by hydrolysis either with acids of low concentration at comparatively high temperatures (Scholler process), or with highly concentrated acids at comparatively low temperatures (Bergius process).

Considerable experimentation has been carried on in this country in attempts to utilize sawdust and mill waste for alcohol production, and at least one attempt was made to produce ethyl alcohol commercially from sawdust (1915). In the early work a dilute sulfuric acid process was used. Yields equivalent to 20 to 24 gallons of 100 percent alcohol per ton of dry coniferous wood were obtained, on small scale production, the yield being considerably less with the wood of broadleaved trees. In plant operation, yields ranged from 10 to 18 gallons of 100 percent alcohol per ton of dry wood. The industrial production of alcohol by this method in the United States has not thus far been demonstrated to be profitable.

Alcohol production from wood wastes has been intensified abroad within the last few years because of improvements in the saccharification procedure. Two processes have been developed in Germany in which high yields of alcohol are claimed. In one of these processes (Scholler) dilute sulfuric acid of 0.2 to 1.0 percent concentration is circulated through layers of sawdust or grated wood chips, under pressure and at a temperature of 170-180° C. A wort containing about 4 percent of sugar is obtained. The free acid is neutralized with lime, and the wort is clarified, after which it is fermented in the usual manner. Yields of about 50 gallons of 100 percent alcohol per ton of dry coniferous wood are obtained, together with considerable quantities of dry yeast and residual lignin. In the second (Bergius) process, concentrated hydrochloric acid is used as the saccharifying agent. The use of concentrated acid requires special acid-resistant material for equipment and necessitates the recovery of the acid, both of which complicate the process and increase the capital charges. The sugar produced in the hydrolysis is easily destroyed by the acid, and must be quickly and continuously removed. For this reason the Bergius process has not been as commercially attractive as the Scholler, especially since the latter process permits variations in degree of hydrolysis. A recent modification of the Scholler process attempts only partial conversion of the cellulose with reduced alcohol yields (18-20 gallons), so as to leave utilizable residues.

The value of conversion processes for wood as a source of alcohol will depend on the cost of the raw material and processing, and on the utilization of residual lignin or ligno-celluloses. The residues are suitable for plastics, in certain instances. Vast amounts of alcohol might be produced from annual wood wastes if an economic process were perfected.

(2) Waste Sulfite Liquors from Paper-Pulp Mills

The liquor obtained as a waste product in the pulping of wood by the sulfite process contains from 2 to 3.5 percent sugars, of which about 65 percent are fermentable to alcohol. Before such a liquor can be fermented, however, the

sulfur dioxide, as well as the acetic and formic acids contained in the solution must be neutralized, usually with lime or calcium carbonate. A special type of yeast which has been acclimated to sulfite liquors is generally used as the fermenting agent. The fermentation yields a quantity of alcohol equivalent on the average to 1 percent of the volume of liquor fermented. Relatively large distillation capacities will be required because these concentrations are only about one-fifth of the usual grain-mash concentrations. The process utilizing this material has never been employed to any great extent in the United States, but it has been an important source of industrial alcohol in the Scandinavian countries and in Germany. New industrial developments utilizing this process are now pending in Canada.

Synthetic Alcohol

In recent years there have been significant increases in the proportionate production of synthetic industrial alcohol, principally from petroleum refinery waste gas, as shown below:

Table 1.- Trends in alcohol production from various raw material sources

Produced from	Year									
	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942[1]
	Percent of total production									
Molasses	83.0	83.4	85.5	76.1	75.7	73.1	67.6	68.5	70.4	68.1
Grain	4.1	6.3	2.7	7.0	8.4	9.1	7.7	5.7	5.9	9.1
Synthetic	9.7	7.3	9.7	16.0	15.2	17.6	23.8	25.1	23.4	21.4
Other	3.2	3.0	2.1	.9	.7	.2	.9	.7	.3	1.4
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

1/ Estimated from current reports.

The present production trend is not accurately reflected by the percentages shown. This is influenced by (a) current shortages of molasses, (b) increases in use of grain as raw material, (c) conversion of the entire beverage-alcohol industry temporarily to industrial-alcohol production for war purposes, and (d) large increases of total production occasioned by the war which exceed the relative increases in synthetic-alcohol production.

Synthetic alcohol is usually made by the separation of ethylene from the gas stream and absorption of the ethylene in sulfuric acid to form ethyl sulfate, which is hydrolyzed to ethyl alcohol. Alcohol can be made by this process at costs equal to or less than molasses fermentation alcohol, and with high purity. However, such alcohol has not been used for beverage purposes, insofar as information is available.

Table 2.- Production of industrial alcohol in the United States in past years[1]

Year	Number of plants	Proof gallons[2]
1933	34	115,609,754
1934	34	165;103,582
1935	32	180,645,920
1936	35	196,126,236
1937	38	223,181,228
1938	36	201,033,858
1939	36	201,017,546
1940	37	243,727,756
1941	39	298,845,417
1942 (Est.)[3]	x[4]	424,000,000

1/ From Department of The Treasury Statistics.

2/ A proof gallon represents one United States wine gallon (231 cu. in.) of 100-proof alcohol, which contains exactly 50 percent alcohol by volume. 1.9 proof gallons = 1 wine gallon of 190-proof (95 percent) alcohol; 2.0 proof gallons = 1 wine gallon of 100 percent alcohol.

3/ Estimated from current non-official information.

4/ Beverage spirits industry also producing industrial alcohol.

Anhydrous or Absolute Alcohol

In recent years there has been an increasing demand in this country for anhydrous (water-free) alcohol for industrial uses, particularly in the lacquer and film industries. In several foreign countries which have been largely or entirely dependent upon imports for supplies of petroleum products, anhydrous alcohol is produced for use in motor fuels. In order that alcohol may be mixed with gasoline, it should not contain more than a few tenths of one percent of water. When ordinary 190-proof alcohol (95 percent) is mixed with a much larger proportion of gasoline, the mixture is likely to separate into two layers at low temperatures unless certain blending agents, such as butyl alcohol, benzol, or acetone, etc., are added.

Commercial processes and equipment have been developed for obtaining alcohol in nearly anhydrous condition from ordinary 190-proof (95 percent) alcohol, or directly from fermented mash. These processes increase the cost of production by not more than 1 or 2 cents a gallon. Many of these processes and equipments are patented, and during the life of the patents can be used only under license, with possible payment of royalties to the patent owners. Process methods include: (1) Azeotropic distillation methods, dependent on the fact that when suitable organic liquids, such as benzol (benzene), trichlorethylene, ether, and volatile mineral spirits (100°-101° benzine), etc. are mixed with high-strength (95 percent) alcohol during distillation, the

water present, with a small proportion of the alcohol, first passes over with the entraining liquid. The remainder of the entraining liquid then distills over with some alcohol, leaving the balance of the alcohol in an anhydrous state. (2) Use of anhydrous materials (such as calcium sulfate, potassium or sodium alcoholate, anhydrous potassium or sodium acetate, or calcined aluminum oxide) to absorb water from a vapor or liquid mixture of alcohol and water. (3) Distillation of the alcohol under a partial vacuum. (4) Recently the treatment of alcohol with exact amounts of ether, so that the ether and water combine to form ethyl alcohol, has been suggested, but is not used commercially.

Cost of Producing Alcohol

The cost of producing alcohol depends upon the location of the manufacturing plant, type of equipment, kind of raw material, price paid for the raw material, relative labor costs, and scale of production. The cost has fluctuated during recent years. It is estimated that under present conditions (1943) the plant-operating (conversion) cost of producing a gallon of 95 percent alcohol from blackstrap cane molasses may be as low as 3 to 4 cents per gallon (exclusive of raw material) for a unit operating at the highest efficiency and producing from 20,000 to 30,000 gallons of alcohol a day. Normally, for smaller operations, the cost may exceed 6 cents. With molasses at ordinary, pre-war price of 5 cents a gallon and with a yield of 1 gallon of 99.5 percent alcohol from 2-1/2 gallons of molasses, the operating and raw material costs would approximate 18-1/2 cents per gallon of alcohol, under good operating conditions.

The operating (conversion) cost for producing alcohol from corn in manufacturing plants of similar capacity is estimated to be between 7.5 and 13.0 cents per gallon, exclusive of malt cost which runs from 2 to 5 cents per gallon of alcohol produced. With corn at 45 cents per bushel (pre-war price for usual distilling grade) and malt at $1.00 per bushel and allowing 12 cents per bushel for the value of the byproduct, and with an estimated yield of 2.50 gallons of 95 percent alcohol per bushel, and use of 8 percent malt, the operating and raw material costs of alcohol from corn are estimated at approximately 30 cents per gallon. These costs do not include sales expense or freight, cost of denaturing, or the cost of distribution. Profits to the producer and retailer must be added to these costs to determine the price per gallon to the consumer. These are merely typical figures and will vary with conditions. It should be emphasized that there is no such thing as a fixed "alcohol cost", for it will vary between plants, and even from day to day in the same plant.

The yield of alcohol obtainable from the various farm crops depends upon the character of the material and the efficiency of operation. Properly selected, treated, and fermented carbohydrate materials upon distillation may be expected to give the yields of alcohol found in table 3. Since usually the materials used for industrial alcohol production are not the highest market grades, an average rather than a high fermentable content is assumed.

Table 3 is intended to show approximately the price (for normal times) at which the various crops must be obtained if they are to compete in alcohol

Table 3.- Estimated values of farm crops in comparison with waste molasses, as alcohol sources
(Basis - 100 wine gallons of anhydrous alcohol produced)

aw material	Amount required units		Price per unit de-livered	Raw material cost	Probable process-ing cost 1/ total	Total cost	Credit for by-products 2/	Net alcohol cost 3/
			Dollars	Dollars	Dollars	Dollars	Dollars	Dollars
olasses (black strap)	250	gals.	0.05 gal.	12.50	8.00	20.50	0.50	20.00
orn	42.5	bu.	.40 bu.	17.00	13.00	30.00	6.50	23.50
rain sorghum	45.0	bu.	.35 bu.	15.75	14.00	29.75	4.50	25.25
heat (hard)	38.3	bu.	.70 bu.	27.16	14.00	41.16	6.10	35.06
otatoes	145	bu.	.10 bu.	14.50	11.00	25.50	1.50	24.00
eetpotatoes	100	bu.	.15 bu.	15.00	10.00	25.00	1.50	23.50
gar beets	4.52	tons	5.00 ton	22.60	9.00	31.60	3.60	28.00
pples	7.00	tons	5.00 ton	35.00	9.50	44.50	5.00	39.50

/ These values represent the summation of a great many variables, and will differ or each plant. Malt costs are included for starchy materials.

/ Fusel oil and byproduct feed (distillers dried grains) only. The feed values ill vary with changes of value of the original raw materials.

/ These values are the net resultant of many variables, and must be considered s tentative. However, the values shown probably reflect the comparative order f cost for the raw material prices used. To equal molasses-alcohol costs, prices aid for raw materials must be correspondingly reduced, unless processing costs re cut or byproduct values are increased.

production with blackstrap molasses at 5 cents a gallon. It should be noted that, although all the respective alcohol costs stated are greater than the molasses-alcohol basis, yet the prices at which the raw materials are computed are below the usual market prices, and in the case of potatoes, for example, represent cull values only. The figures in this table do not include differences in transportation costs and general items not ordinarily included as processing costs. They are based on the relative carbohydrate content of the particular commodity plus an estimated conversion cost, with estimated byproduct credit allowances. Blackstrap molasses has sold as low as 3 cents and as high as 8 cents a gallon, and occasionally, even higher. Five cents a gallon is taken as a fair price for comparison with other potential alcohol sources. (Present war prices of blackstrap molasses have reached 19 cents per gallon, making this product uneconomic in comparison with corn at around 85 cents per bushel).

Alcohol Plant Costs

Owing to variations in the cost of material and labor, it is impossible to indicate exactly the probable cost of erecting and equipping an alcohol plant. Estimates may be obtained from firms engaged in the manufacture and erection of distillery apparatus and from consulting engineers who give special attention to the construction of such plants. Such costs for simple molasses plants have been estimated in the past at approximately $50.00 capital investment for each gallon of product per day. Grain-plant costs may run from $75.00 to $125.00 per daily gallon output, depending on the amount of automatic control or other desirable features that are incorporated in the arrangement. Some idea of the equipment requirements may be obtained from the following list.

Alcohol Plant Equipment Requirements
(From Grain)

- Railroad sidings, docks
- Track scales
- Raw material
    - Unloading, weighing, cleaning, storing, conveying
- Buildings and services. (Water, sewers, etc.)
    - Repair shops
    - Locker rooms
- Boiler plant
    - Control, recording instruments and accessories
    - Fuel and ash handling
    - Water treatment
    - Dynamo, air compressor, meters, motors
- Processing
    - Grain handling and milling
    - Cooking apparatus
    - Malt preparation
    - Yeast preparation
    - Mash coolers

Fermentation vessels
Drop tubs (beer wells)
Carbon dioxide scrubber
Hot water storage (reuse)
Mash, beer and slop pumps
Distillation unit
  Beer column
  Aldehyde or "heads" column
  Rectifying column
  Stripping column
  Anhydrous column
  Accessories, recording meters, etc.
Process tanks (alcohol)
Alcohol storage (bonded warehouse)
  Alcohol scales, pumps, etc.
Slop recovery
  Screen
  Press
  Drier
  Evaporator
  Pumps, recorders
  Accessories
"Grains" bins
Bagging chute
Sirup storage
Slop tanks
Scales

Control laboratories

Denaturing plant
  Storage tanks, scales, pumps

Alcohol from Waste Products of the Farm

The suggestion has been made that the manufacture of industrial or denatured alcohol on the farm would provide a means for the farmer to dispose advantageously of certain crop surpluses and wastes, the derived alcohol being utilized as a motor fuel, etc., on the farm. A careful analysis of all the factors entering into the question leads to the conclusion that there is little likelihood that home distilleries of present conventional design can be operated with satisfaction or profit. The main reasons for such a conclusion are: (a) a fermentation process must be carefully controlled if a satisfactory yield is to be obtained, and the average farmer does not have sufficient technical training or equipment to do this effectively; (b) the cost of installation of the small manufacturing unit is relatively high; (c) the labor cost is actually excessive and the output small; (d) the supply of raw material is likely to be both variable and intermittent; (e) storage of available raw material is difficult; and (f) the unit cost of production will be so high that the farmer can ordinarily buy industrial alcohol cheaper than he can make it. Furthermore, existing laws must be modified or repealed before such operations would have a legal status. The value of the feed residues from such process has been perhaps overstressed since these are not likely to exceed the value of the original materials.

It has also been proposed that fermentable farm culls be utilized in central distilleries for the production of alcohol. Such a plan has greater merit, although the economics are debatable, principally for the reason that cull materials usually have a relatively low content of fermentable matter. Transportation charges of the raw material may be practically prohibitive if it is necessary to bring such low-grade material from a distance to a central point. Continued supplies of certain materials might be difficult to obtain to assure year-round operation. Rather large scale operation is necessary to permit carrying adequate trained personnel. Extensive research and study on this type of operation will have to be made, and present conventional processes may have to be modified.

The present commercial production of ethyl alcohol from molasses, grain, or by synthesis, sets a competitive price standard which must be met. Crop surpluses, culls, and wastes usually constitute poor material which is relatively unsaleable in standard market grades. Such material may be low in carbohydrate content, and may contain dirt, excess moisture, fungi or molds, etc. The relative cost of the alcohol produced from such sources will probably be high, or the quality poor, at least in regard to odor and taste. Many of the possible cull materials are perishable and will be lost unless processed with reasonable speed. Moreover, surpluses vary in quantity from year to year. A program of alcohol production from these materials involves the maintenance of alcohol plants and personnel at central points, and such plants must have enough available raw materials to assure year-round operation for every year. It is not economical to build expensive alcohol plants and then depend on sporadic operation as cull or surplus materials become available. Plants with relatively low outputs of 2,000-2,500 gallons per day would find it difficult to maintain adequate technical supervision without incurring relatively high per-gallon costs.

Alcohol Motor Fuel

Because of the quality of the alcohol likely to be produced from lower grade farm surplus materials, the possibility of use of such alcohol as a motor fuel ingredient has been considered. The employment of motor fuel secured from annually renewable agricultural sources would utilize the interaction of sunshine, soil, air, and water as power, and conserve irreplacable national petroleum deposits. Such a program would however involve far reaching economic changes, the implications and possibilities of which are now being studied. Some of the problems involved have been discussed in detail in Senate Document #57, a report of the Secretary of Agriculture to the Senate on the agricultural motor fuel problem, and in U. S. Department of Agriculture Miscellaneous Publication No. 327, entitled "Motor Fuels from Farm Products", as well as elsewhere.[1] The production cost of alcohol must be considerably reduced before it can compete on an economic basis with gasoline, at present prices, but diminishing petroleum reserves will probably increase the price of gasoline in the years to come. Some advantage may accrue from the use of

---

1/ See bibliography attached.

alcohol to raise the octane rating or antiknock value of the lower grades of gasoline, as now manufactured. However, in view of present wartime demands for alcohol, especially for munitions and synthetic rubber, such proposals must be deferred until after the war.

Some idea of the problem can be visualized from the following. Assuming that 15 percent of any carbohydrate food crop normally represents available culls, surplus, and waste, then the estimated total alcohol obtainable from all the grain, fruit, and other carbohydrate crop surpluses and wastes (22 crops) at the above percentage (based on 1936 crops) is 1,650,000,000 gallons, assuming that it were possible to collect and successfully process all this material. Gasoline consumption in 1941 was over 26.7 billion gallons annually. Therefore, the use of this vast amount of raw material to produce alcohol would represent only about a 6.2 percent alcohol-gasoline blend of the entire motor fuel used. Assuming further that an alcohol plant of economic size produces 20,000 gallons per day or 6,000,000 gallons per 300-day year, about 275 such alcohol plants would be required to produce the above quantity, or 445 plants for a national 10 percent blend. The total pre-war production capacity of the industrial alcohol industry was about 250,000,000 wine gallons annually, divided among 35 to 39 plants of various sizes. The pre-war production capacity of beverage alcohol plants was about the same, with approximately 100 plants of various sizes operating. Expansions have taken place, and new plants have come into production, but it is doubtful if the total production capacity of all existing industrial and beverage plants could exceed 750 million gallons annually. Considering anticipated industrial requirements for alcohol, the existing industrial alcohol and beverage industries would have to be quadrupled to make sufficient alcohol for a national 10 percent alcohol gasoline blend. Based on corn alone, a billion bushels, or over one-third of a normal crop, would have to be used to make the necessary alcohol.

Under the normal agricultural system, occasional large crops produce an unsold surplus, which disturbs the price structure. If the crop is perishable the result is a loss to the farmer, either directly on the unsold amount, or indirectly through the depressed market price. If the crop is nonperishable the hold-over surplus may affect the market in subsequent years. As a rule, in normal as well as in bumper years, accumulations of culls of certain crops occur at specific sorting or shipping points, and these, as well as the crop surpluses, need a market outlet or some economic method of utilization. But such outlet or utilization must not disturb existing industry unduly. Because of the large potential amounts involved, the motor fuel outlet, by a fortuitous circumstance, seems to be the one possible industrial use which in normal times might be able to absorb these surpluses, if the matter of comparative price were adjusted. Synthetic rubber production might also afford an outlet for several hundred million gallons of alcohol. The whole problem is as much an economic as a technical one.

Behavior of Ethyl Alcohol in an Internal Combustion Engine

In comparison with about 18,900 B.t.u.[1] for usual motor grade gasoline, the net heat of combustion of anhydrous alcohol is only about 11,520 B.t.u. per pound. However, the actual fuel air mixture, as drawn into the engine, will run about the same in B.t.u. value (100 B.t.u. per cu. ft.) for both alcohol and gasoline. While alcohol has only approximately 60 percent of the fuel or power value of gasoline, it can be employed at higher compression ratios, resulting in a net yield of power greater than the indicated value. Alcohol burns cleanly, without formation of carbon. Alcohol has a higher viscosity, but a lower flame temperature and different flame propagation rate, as well as a different boiling characteristic than gasoline. Thus considerably different conditions are set up within the engine when alcohol or alcohol blends are used. Alcohol, when added to gasoline, increases the "octane rating" to a variable degree depending on the gasoline. To secure maximum effect of alcohol, however, compression ratios should be increased and carburetor jet size increased. In the average car using modern, higher compression ratios, blends of alcohol up to 10 percent would probably function about as efficiently as high-test gasoline without much noticeable variation in performance of the motor. Blends containing larger percentages of alcohol may show decreased mileage per gallon of fuel used. Presence of alcohol in the fuel will tend to remove deposited water in fuel systems, avoiding freezing of lines in cold weather. Alcohol has a tendency to clean the gum from fuel lines, and to burn carbon from dirty engines, and may thus improve the existing efficiency of an old car by such cleaning action. Because of the presumable interchangeability of 10 percent blends and straight gasoline in modern cars, it might not be necessary to effect blending on a national scale, as previously implied, as long as all blends were uniform.

Alcohol Motor Fuel Abroad

Previous to the war, alcohol was used as a constituent of automobile fuels in Germany, France, Hungary, Sweden, Czechoslovakia, Cuba, and the Philippine Islands, and to a small extent in Australia, China, Great Britain (United Kingdom), and certain other foreign countries. All these countries were largely or entirely dependent upon imports for supplies of petroleum or petroleum products. Australia, Argentina, and other countries at the same time were confronted with large grain surpluses. In Germany, Italy, France, and other European countries which possessed comparatively small petroleum resources, the problem of replacement or substitute fuel was involved in questions of national defense and national self-sufficiency, and consequently efforts were made to find suitable sources of fuel. Germany at one time used more alcohol for motor fuel than all other countries combined. The motor fuel industry was required to purchase alcohol in proportion to the quantity of other motor fuel handled; the proportion at first was only 2-1/2 percent of imports or sales but was progressively raised until on October 1, 1932 it

[1] Fuel in liquid state, (water of combustion considered in vapor stage).

reached 10 percent; it remained there for several years and then decreased. Motor fuel in Germany in more recent years was a complex and varying mixture of compounds produced largely by synthetic means from many source materials such as coal, wood, and oil.

The use of alcohol motor fuel was reported to be technically satisfactory in Germany as far as car operation is concerned. Some loss of power was reported in small, low-compression motors, but favorable results were obtained in higher compression motors. The chief advantage in its use was its "anti-knock" (octane rating) effect. But, according to consular reports, alcohol motor fuel was found to be distinctly uneconomical. While benefiting only a relatively restricted part of the population, notably the potato growers and distilleries situated chiefly in eastern Germany, it had adverse effects in increasing the already high cost of motor fuel and thus retarding the country's motorization, while in addition lessening Government income.

Blending Agents for Alcohol Fuels

Gasoline and ordinary 95 percent alcohol do not form a stable mixture; they separate into two layers when the temperature is lowered or when water is added, even in small amounts. However, when 99.5 percent alcohol is used, the mixture becomes relatively more permanent. To avoid separation, "blending agents", such as butyl alcohol, acetone, and benzol, can be added to commercial power alcohol-gasoline blends to increase the water tolerance of the mixture. These blending agents usually have better fuel values than ethyl alcohol, and some of them, such as butyl, isopropyl or amyl alcohols, acetone, and ether, can be produced from farm crops.

Future Replacement Fuels from other Sources

Ethyl alcohol is made synthetically from ethylene gas by absorbing this gas in concentrated sulfuric acid, with subsequent hydrolysis. Other alcohols can be made by the same process from various gases chemically associated with ethylene. Most of these gases occur as a byproduct in the "cracking" of crude petroleum into gasoline. Alcohols may also be synthesized from carbon monoxide and hydrogen gas, by passage over a suitable catalyst at high temperature and pressure, the particular alcohol product being determined by the conditions of the reaction and the percentage composition of the gas mixture. These gases are obtainable from coal, coke, and other sources. Methanol (wood alcohol) is now commercially produced synthetically by such process, but production of higher alcohols by such means has not yet become commercial. Much development along this line may be anticipated.

Future motor fuels may also be derived from wood; shale oil; from the hydrogenation of coal; by polymerization of gases (such as waste gas from petroleum cracking processes, natural gas, blau gas, or similar low-cost sources); or even from solid fuels such as carbon. For operating the engines on motor vehicles, solid fuel may be changed to a burnable gas by means of a generating system attached to the vehicle; it might also be possible to generate power by explosions of minute charges of a solid fuel within a

specially designed engine. Because of war conditions abroad and the consequent scarcity of gasoline, there has been much development of such motor propulsion methods, particularly in England and Germany with gas generator types of engines. It may be anticipated that under post-war conditions the automotive industry will take any steps necessary to keep abreast of any change in the fuel situation, and the likelihood is that any change will be one of gradual evolution.

Laws and Regulations Governing Manufacture and Sale of Industrial Alcohol

Acts of Congress of June 7, 1906, March 2, 1907, and October 3, 1913, permit the manufacture and sale of domestic alcohol for use in the arts and industries and for fuel, light, and power, without the payment of internal revenue tax, provided the alcohol has been produced under government supervision and blended in the presence and under the direction of authorized government officers with approved denaturing materials which destroy its usefulness as a beverage or render it unfit for liquid medicinal purposes. Since the repeal of the Eighteenth Amendment and the creation of the Alcohol Tax Unit in the Bureau of Internal Revenue, the above laws have been somewhat changed and modified. Industrial alcohol plants are not allowed to operate until a permit has been obtained and all the requirements of the law and regulations have been complied with. Information pertaining to the manufacture and sale of alcohol may be obtained from the Commissioner of Internal Revenue, U.S. Treasury Department, Washington, D. C.

Industrial Uses for Alcohol

Ethyl alcohol is used extensively in a large number of manufacturing operations, as a starting material for synthetic products, as a processing solvent, or as an ingredient of product formulae. Lacquers, varnishes, wood stains, medicinal extracts, flavoring extracts, perfumes, organic chemicals, oilcloths, imitation leather, special soaps, embalming fluids, photographic materials, celluloid, smokeless powder and other explosives, dyes, ink, and fuel are a few of the articles in the manufacture of which alcohol is employed. It is also extensively employed to prevent freezing in automobile radiators. Recent uses involve the production of butadiene (gas) from alcohol by catalysis, the butadiene being then incorporated with styrene to form synthetic (Buna type) rubber.

Sources of Further Information

Data on special phases of the alcohol question may be obtained by consulting the following sources of information:

(1) Current prices of blackstrap molasses and of industrial alcohol:- Monthly issues of Chemical Industries, published by Chemical Markets, Inc., Pittsfield, Mass., or Oil, Paint and Drug Reporter, (weekly) published by Schnell Publishing Co., New York, N. Y.

(2) Distillery equipment: J. P. Devine Manufacturing Co., Mt. Vernon, Ill.; E. B. Badger & Sons Co., Boston, Mass.; Blaw-Knox Company, Pittsburgh, Pa.; Buffalo Foundry and Machine Co., Buffalo, New York; Vulcan Copper and Supply Company, Cincinnati, Ohio; Ansonia Copper & Iron Works, Inc., Cincinnati, Ohio; The Lummus Company, New York, N. Y.; Acme Coppersmithing & Machine Company, Oreland, Pennsylvania; Atlas Copper and Brass Manufacturing Company, Chicago, Ill.; Theo. Walter Copper Works, Inc., Newark, N. J.; Oscar Krenz Copper & Brass Works, San Francisco, California. Some firms will normally undertake to furnish complete installations.

In giving the names of these firms no guaranty is implied, nor is it to be understood that these firms are recommended over others who may be engaged in the same line of business but whose names are not listed. The names have been obtained from commercial registers of manufacturers for the information and assistance of correspondents. It must be understood that under war conditions, plants can be built or expanded only under government authorization.

Articles, Books, and Government Bulletins on Alcohol

The publications listed below may be consulted in any well-equipped library. Where a price is given, indicating that supplies are still available for distribution, government publications may be purchased from the Superintendent of Documents, Washington, D. C. Prepayment is required and should be made in cash (exact amount) or by postal or express money order payable to the Superintendent of Documents.

(1) Government publications

U. S. Department of Agriculture

Manufacture of Denatured Alcohol Based on the Operations of an Experimental Still at Washington, D. C., Bureau of Chemistry Bulletin 130 (1910). Out of print. (Discusses experimental work on the production of alcohol from farm waste.)

Industrial Alcohol; Uses and Statistics, Farmers' Bulletin 269 (1906). Out of print. (Presents several uses for ethyl alcohol on the farm and in the industries, as well as statistical data on production.)

Potato Culls as a Source of Industrial Alcohol, Farmers' Bulletin 410 (1910). Out of print. (Describes apparatus and methods employed in the manufacture of denatured alcohol from cull potatoes.)

Agricultural Alcohol; Studies of its manufacture in Germany, Department Bulletin 182 (1915). Out of print. (Covers mainly the economic features of ethyl alcohol production from potatoes in Germany. No technological details are given.)

Industrial Alcohol; Sources and Manufacture, Farmers' Bulletin 429 (1911). Out of print.

The Manufacture of Ethyl Alcohol from Wood Waste, Department Bulletin 983 (1922). Out of print. (Contains a survey of commercial possibilities and a detailed description of experiments to determine optimum conditions of manufacture.)

Tests of Internal-Combustion Engines on Alcohol Fuel, Office of Experiment Stations Bulletin 191 (1907). Out of print. (A technical description of tests on several low- and high-speed engines.)

The Use of Alcohol and Gasoline in Farm Engines, Farmers' Bulletin 277 (1907). Out of print. (Describes experiments to determine what can be accomplished with alcohol in existing engines and what changes in the mechanism are necessary to secure the highest efficiency in the use of alcohol as a fuel.

Motor Fuels from Farm Products, Miscellaneous Publication No. 327 (1938). Price 15 cents. (Discussion of the alcohol motor fuel problem, including crop information, alcohol plant construction, operation and costs, other fuels, and general economics.)

Other

Use of Alcohol from Farm Products in Motor Fuel, Senate Document 57, 73rd Congress, 1st Session (1933). Price 5 cents.

Use of Alcohol from Farm Products in Motor Fuel, Senate Document. Hearings on S.552, a bill to provide removal of federal tax on alcohol motor fuels. May 23-25, 29, 1939, before A Subcommittee of the Committee on Finance, U. S. Senate.

Utilization of Farm Crops for Industrial Alcohol and Synthetic Rubber. (3 Vols.) (1942), Hearings on S.224, before a Subcommittee of the Committee on Agriculture and Forestry, U. S. Senate. (Hearings continuing, 1943, Vols. 4-5, etc.).

U. S. Department of Interior

Commercial Deductions from Comparisons of Gasoline and Alcohol Tests on Internal-Combustion Engines, Bureau of Mines Bulletin 32 (1911). Out of print. (Discusses behavior of alcohol as a motor fuel.)

Fuel Values of Gasoline and Denatured Alcohol, Bureau of Mines Bulletin 43 (1912). Out of print. (Detailed description and discussion of engine tests.)

Copies of Patents: The United States Patent Office, Washington, D.C., will supply copies of specifications for United States patents at 10 cents each and information in regard to the procedure in securing copies of any foreign patents covering processes for the manufacture of alcohol from various raw materials. Some libraries maintain files of the more important patents on various subjects, which may be consulted.

(2) General Books and Articles

Alcohol, C. Simmonds, MacMillan and Co., Ltd., London, (1919), pp. 558.

Industrial and Power Alcohol, R. C. Farmer, I. Pitman and Sons, Ltd., New York, London, (1921), pp. 110.

Power Alcohol, G. W. Monier-Williams, Oxford University Press (American Branch), 35 W. 32nd St., New York, (1922), pp. 323.

Alcohol in Commerce and Industry, C. Simmonds, I. Pitman and Sons, London, (1922), pp. 119.

Industrial Alcohol, A. E. Williams, Engineering, Vol. 140, pp. 27-29, 53-54 (1935) (article).

The Internal Combustion Engine, C. F. Taylor and E. S. Taylor, 1st Ed. (1938). International Textbook Co., Scranton, Pa.

Power Alcohol: History and Analyses, 1940. Committee on Motor Fuels, American Petroleum Institute.

Power Alcohol from Farm Products, Its Chemistry, Engineering and Economics. Iowa Agricultural Experiment Station, Ames, Iowa, 1940. Contributions from Iowa Corn Research Institute, Vol. 1, No. 3, pp. 283-375.

Industrial Chemistry, E. R. Riegel, 4th Ed. (1942) Reinhold Publishing Company, New York.

(3) Raw Materials

Alcohol from Potatoes, A. E. Williams, Chem. Trade Jour. and Chem. Eng., Vol. 93, pp. 335-36 (1933) (article).

Yearbooks, U.S. Dept. of Agric. Statistical Supplements.

(4) Production

Ethyl Alcohol Industry Improves its Distillation Processes, G. T. Reich, Chem. and Met. Eng., Vol. 36, pp. 716-719 (1929) (article).

Distilling Beverages from Grain, G. T. Reich, Chem. and Met. Eng., Vol. 40, pp. 618-624 (1933) (article).

The Technical Control of Modern Distilleries, J. Perard, Bull. Assoc. Chim., Vol. 54, pp. 425-437 (1937) (article).

Technology Transcends Heritage in Modern Distillery Practice, C. S. Boruff and L. P. Weiner, Chem. and Met. Eng., Vol. 44, pp. 192-5 (1937) (article).

Food for Thought, H. F. Willkie and P. J. Kolochov, (1942) Indiana Farm Bureau, Inc., Indianapolis, Ind. (With Jos. E. Seagram and Sons Co.)

A Modern Distillery (Flow sheet), Chem. and Met. Eng., Vol. 49, November 1942, pp. 126-129 (article).

The Production of Ethyl Alcohol from Cull Potatoes and Other Farm Crops, H. Beresford and L. M. Christensen, Idaho Agricultural Experiment Station Bulletin 241 (September 1941).

(5) Dehydration

Improvements in the Production of Absolute Alcohol, H. Guinot, International Sugar Journal, Vol. 36, p. 24 (1934) (article).

Modern Methods for the Production of Absolute Alcohol, R. Fritzweiler and K. R. Dietrich, Chem. Engr. Cong. World Power Conference, (1936), Advance Proof No. C 4.

(6) Alcohol as a fuel (articles)

Researches on Alcohol as an Engine Fuel, H. B. Dixon, Jour. Soc. Automotive Engineers, Vol. 7, pp. 521-524 (1920).

The Combustion of Fuels in the Internal Combustion Engine, T. Midgley, Jour. Soc. Automotive Engineers, Vol. 7, pp. 489-497 (1920).

Alcohol for Motor Fuel, Jour. Soc. Automotive Engineers, Vol. 10, pp. 364-5 (1922).

Performance Tests of Alcohol-Gasoline Fuel Blends, R. B. Gray, Agricultural Engineering, Vol. 14, p. 135 (1933).

Alcohol Gasoline Blends, Leo M. Christensen, Ind. Eng. Chem. Vol. 28, pp. 1089-1094 (1936).

Alcohol Gasoline as Motor Fuel, Benjamin T. Brooks, Ind. Eng.Chem. Vol. 28, pp. 1361-1362 (1936).

Utilization of Ethanol-Gasoline Blends as Motor Fuels, O. C. Bridgeman, Ind. Eng. Chem., Vol. 28, pp. 1102-1112 (1936).

Alcohol Motor Fuels, A. R. Ogston, J. Inst. Petroleum Technologists, Vol. 23, pp. 506-523 (1937).

(7) Synthetic Alcohol

Improved Mode of Manufacturing Alcohol from Olefiant Gas, E. A. Cotelle, U. S. Patent 41,685 (1864).

Process for the Production of Alcohol from Gas Containing Ethylene, C. A. Basore, U. S. Patent 1,385,515 (1921).

Process for the Sulfation of Ethylene and the Sulfation of a Mixture of Ethylene and Propylene, B. T. Brooks, U. S. Patent 1,885,585 (1932).

Process of Making Ethyl Alcohol, B. T. Brooks, U. S. Patent 1,919,618 (1933).

Synthetic Alcohols and Related Products from Petroleum, B. T. Brooks, Ind. and Eng. Chem., Vol. 27, pp. 278-288 (1935) (article).

(8) Wood Saccharification - Sulfite Liquor

Method of Treating Products of Hydrolysis of Cellulose, Friedrich Bergius, U. S. Patent 1,547,893 (1925).

Process of Converting Cellulose and the Like into Sugar with Dilute Acids Under Pressure, Heinrich Scholler and Walter Karsch, U. S. Patent 1,990,097 (1935).

Apparatus for the Saccharification of Cellulose, Heinrich Scholler, U. S. Patent 2,086,963 (1937).

Chemical Utilization of Wood Waste, Robert S. Aries, Chemical Industries, Vol. 51, August 1942, pp. 190-197 (article).

Wood as a Chemical Raw Product, Chemistry and Industry, Vol. 59, September 28, 1940, pp. 671-675 (article).

Ethyl Alcohol from Sulfite Waste Liquor, F. S. Hanson, Paper Trade Journal, Vol. 115, No. 24, December 10, 1942, pp. 37-40 (article).

(9) Other Replacement Fuels

The Polymerization of Gaseous Olefines as a Source of Liquid Fuels, A. R. Brown and A. W. Nash, World Petroleum Congress, London, 1933. Proceedings, Vol. II, pp. 774-780 (article).

The Synthetic Production of Motor Fuels According to the Fischer Process, R. Perrautt, Rev. Industrielle, Vol. 65, 373-6 (1935); Chem. Zentr. 1936, I, 2011 (article).

Plant for the Production of Gasoline by the Hydrogenation of Bituminous Coal, F. E. Smith, Proc. Inst. Mech. Engrs. (London), Vol. 133, pp. 139-67 (1936) (article).